REPORT No. 439

WIND-TUNNEL RESEARCH COMPARING LATERAL CONTROL DEVICES, PARTICULARLY AT HIGH ANGLES OF ATTACK

V—SPOILERS AND AILERONS ON RECTANGULAR WINGS

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SUMMARY

This report covers the fifth of a series of systematic investigations in which lateral control devices are compared with particular reference to their effectiveness at high angles of attack. The present report deals with tests of spoilers and ordinary ailerons on rectangular Clark Y wing models. In an effort to obtain satisfactory control throughout the entire angle-of-attack range that can be maintained in flight, various spoilers were tested in combination with two sizes of previously tested ordinary ailerons—one of average proportions and the other short and wide. In addition, one large spoiler was tested alone.

It was found that when ailerons and spoilers are used together the full effect of both is not obtained if the spoilers are located directly in front of the ailerons. With the proper combination of spoiler and aileron, however, it is possible to obtain satisfactory rolling control up to high angles of attack (15° to 20°), together with favorable yawing moments and small control forces. A moderate amount of rolling control with favorable yawing moments and small control forces was obtained with the large spoiler alone.

INTRODUCTION

This is the fifth of a series of reports giving the results of investigations in which it is hoped to compare all types of lateral control devices which have been satisfactorily used or which show reasonable promise of being effective. In this program it is planned first to test the various types of ailerons and other control devices on rectangular wings of aspect ratio 6. Later the best of these control devices are to be tested on wings of different shape. In the entire series the various devices are to be subjected to the same program of wind-tunnel tests which, it is thought, include all the factors directly connected with lateral control and stability that can be satisfactorily handled in a routine manner in a wind tunnel. The tests are designed to show the relative merits of the various control devices in regard to lateral controllability, lateral stability, and general usefulness. They include regular 6-component force tests with the control devices both neutral and deflected various amounts, rotation tests in which the model is rotated about the tunnel axis and the rolling moment measured, and free rotation tests showing the range and rate of autorotation. Because of the large effect of yaw on lateral stability, the tests are made not only at 0° yaw, but also with an angle of yaw of 20°, which represents the conditions in a fairly severe sideslip.

The first report of this series (reference 1) deals with three sizes of ordinary ailerons. One of these is a medium-sized one taken from the average of a number of conventional airplanes and is used as the standard of comparison throughout the entire investigation. Other work that has been done in this series is reported in references 2, 3, and 4.

The present report covers tests of a spoiler as the sole means of lateral control, and also tests of spoilers used in combination with ordinary ailerons. The spoilers were included in the program after preliminary tests (references 5 and 6) had shown that they have certain desirable features in regard to control at high angles of attack, favorable yawing moments, and small hinge moments, and that the adverse rolling moments found with small spoiler deflections in previous tests (reference 7) could be eliminated by locating the spoiler some distance back from the leading edge of the airfoil.

Ordinary ailerons of average proportions (25 per cent of the wing chord by 40 per cent of the semispan) do not give satisfactory rolling moments or yawing moments at the high angles of attack. (Reference 1.) If the ailerons are given a short, wide form, rigged up 10° when neutral, and operated with an extreme differential motion, reasonably satisfactory rolling and yawing moments can be obtained at high angles of attack but high control forces are required. (Reference 3.) In the present tests various combinations of spoilers were tried with both standard size and short, wide ailerons with the object of improving their operation where this seemed desirable. In some cases the spoilers were hinged at their rear edges with the idea

that in practice they would be coupled to the ailerons in such a manner as to oppose the aileron hinge moments and reduce the control force required. Hinge moments were measured for the spoiler operating alone and also for one representative case of a spoiler and aileron operating simultaneously. The results for the various combinations are compared by means of a number of criterions that are being used throughout the entire investigation.

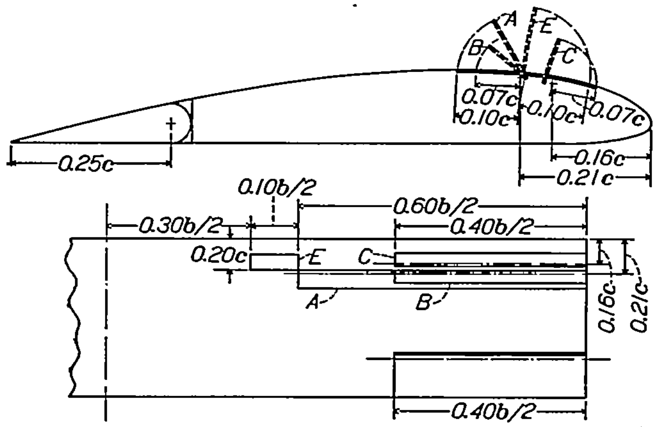

FIGURE 1.—Clark Y wing with plain ailerons 25 per cent c by 40 per cent $b/2$ and spoiler arrangements

APPARATUS AND METHODS

Wind tunnel.—The N. A. C. A. 7 by 10 foot wind tunnel, which is being used throughout the entire investigation, has an open jet and a single closed return passage. The tunnel, together with the regular balance and associated apparatus, is described in detail in reference 8. The hinge moments of the spoilers were measured by means of the calibrated twist of a long slender torque rod extending along the hinge axis from the spoiler to the balance frame outside the air jet. The same method was used for measuring the hinge moments of one aileron.

Models.—The wing models were similar to two of those used in reference 1. They were of rectangular plan form with a 10-inch chord, a 60-inch span, and a Clark Y airfoil section. One had ailerons 25 per cent of the chord by 40 per cent of the semispan, and these ailerons with equal up-and-down deflection of 25° are considered the standard of comparison for the entire investigation. The rolling moment with these ailerons at an angle of attack of 10° is considered to have a satisfactory value. The other wings had short, wide ailerons 40 per cent of the chord by 30 per cent of the semispan, which were designed to give approximately the same rolling moment at the 10° angle of attack. Two model wings with the short, wide ailerons were used in the tests, the first one being replaced because it had a maximum lift coefficient about 5 per cent lower than the other Clark Y wings.

The spoilers were made of steel plate one thirty-second inch thick and were set into the wings in such a manner that the upper surface was continuous when the spoiler was down. The various spoilers and ailerons are shown in Figures 1 and 2.

Because in the spoiler and aileron combinations the spoilers were designed to be raised only when the ailerons behind them were given an upward deflection, the tests herein reported were made only with the aileron deflected upward. The values for the down aileron for the various combinations were taken from previous tests on the same ailerons. (Reference 1.) In every case with a spoiler and aileron combined, a linkage was assumed such that the deflection of the spoiler was proportional to that of the up aileron.

TESTS AND RESULTS

All the tests were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to an air speed of 80 miles per hour under standard atmospheric conditions. The Reynolds Number is 609,000, based on the 10-inch wing chord.

The results are given as absolute coefficients of the forces and moments:

$$C_L = \frac{\text{lift}}{q\,S}$$

$$C_D = \frac{\text{drag}}{q\,S}$$

$$C_l' = \frac{\text{rolling moment}}{q\,b\,S}$$

$$C_n' = \frac{\text{yawing moment}}{q\,b\,S}$$

$$C_H = \frac{\text{hinge moment}}{q\,c\,S}$$

where S is the total wing area, b is the span, c is the chord, and q is the dynamic pressure. Except for the hinge-moment coefficient, the coefficients as given above are obtained directly from the balance and refer to the wind (tunnel) axes. In special cases in the discussion where the moments are used with reference to the body axes, the coefficients are not primed.

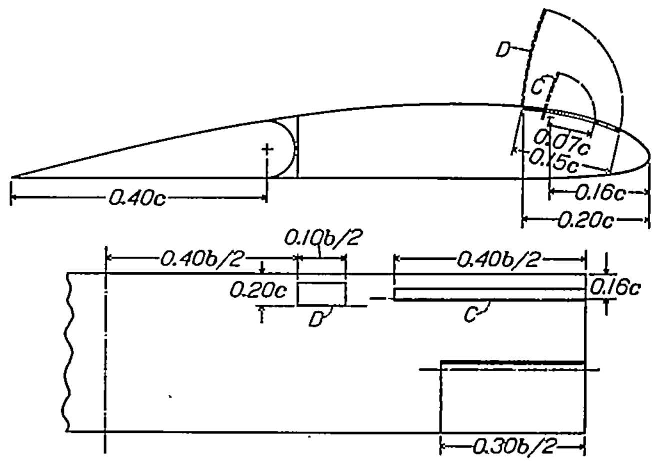

FIGURE 2.—Clark Y wing with plain ailerons 40 per cent c by 30 per cent $b/2$ and spoiler arrangements

Thus the symbols for the rolling moment and yawing moment coefficients about the body axes are C_l and C_n.

Preliminary tests to find best location of rear-hinge spoiler along chord of wing.—Previous tests in the vertical tunnel (reference 5) showed that with a spoiler hinged at its front edge the best results were obtained with the hinge axis in the upper surface of the airfoil about 20 per cent of the chord back of the leading edge. No such tests had been made, however, for a rear-hinge spoiler.

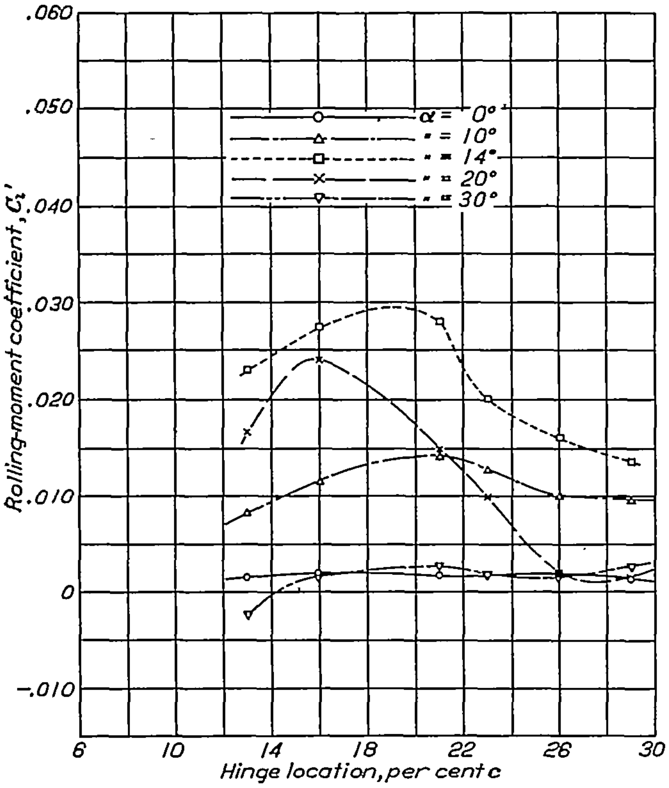

FIGURE 3.—Effect of location on rolling-moment coefficients. Spoiler C up 10°

The air force tends to raise the rear-hinge spoiler. Interconnecting the spoiler with the aileron enables the spoiler hinge moments to be used to balance the aileron hinge moments and reduce the control force required. For this reason it was decided to include rear-hinge spoilers in the investigation, and preliminary tests were made in the 5-foot vertical tunnel (tunnel and set-up described in reference 5) with a spoiler 7 per cent of the chord in width and 40 per cent of the semispan in length (spoiler C) located at various positions along the chord of the airfoil. Inasmuch as the position along the chord is of interest mainly from the consideration of adverse rolling moments with low deflections, the tests were made with the spoiler deflected only 10°. From the results, which are shown in Figure 3, it was decided that the best position was with the hinge axis 16 per cent of the chord back of the leading edge. This arrangement places the front edge of the closed spoiler 9 per cent of the chord from the leading edge.

Large spoiler alone.—The preliminary tests of reference 5 indicated that a spoiler 10 per cent of the chord by 60 per cent of the semispan should give rolling moments of approximately the assumed satisfactory value at an angle of attack of 10°, the highest angle of attack at which the standard ailerons give satisfactory rolling moments. A front-hinge spoiler of this size was mounted in the wing with standard size ailerons, the spoiler hinge axis being 21 per cent of the chord back from the leading edge and 1 per cent of the chord below the surface. (Spoiler A, fig. 1.) Force tests at various angles of attack were made with the ailerons neutral and the spoiler set at various deflections from 0° to 90°. The rolling and yawing moment coefficients are plotted against angle of attack for the various spoiler deflections in Figure 4. In addition, one run was made with an angle of yaw of 20° and a spoiler deflection of 60°, the latter being the assumed maximum deflection based on an examination of the results, all of which are given in Table I.

Inasmuch as this spoiler gave within 80 per cent of the assumed satisfactory rolling control at angles of attack from the stall through 20° and at the same time gave strong yawing moments in the favorable

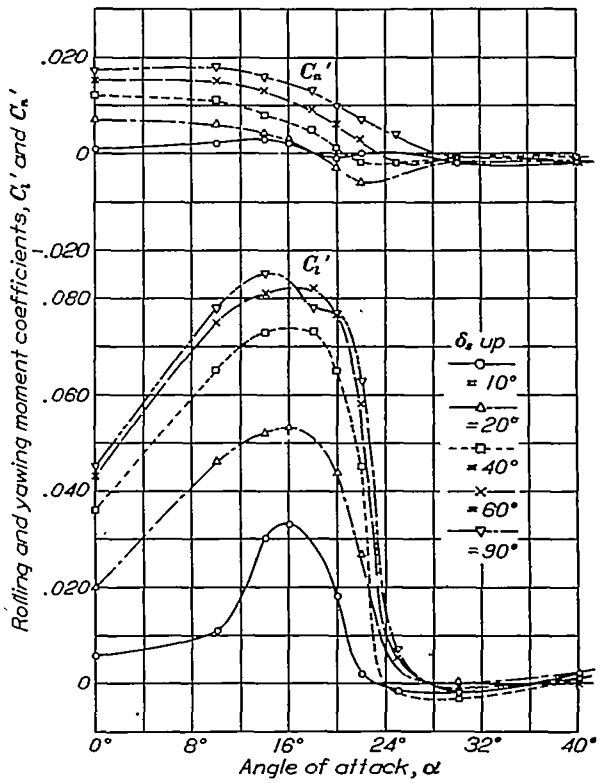

FIGURE 4.—Rolling and yawing moment coefficients due to spoiler A

sense, it was thought desirable to measure the hinge moments also. The hinge-moment coefficients are therefore given for the various spoiler deflections in Table II.

Spoilers and standard size ailerons.—The standard size ailerons give unsatisfactory control at angles of

attack above about 10°, whereas the spoilers give higher rolling moment coefficients near the stall than at lower angles of attack. The ailerons were consequently combined with various spoilers with the idea of obtaining satisfactory values of both rolling and yawing moments throughout the entire angle-of-attack range. The first spoiler tested had a width 7 per cent of the wing chord and a length 40 per cent of the semispan. It was hinged at the front edge, the axis being 21 per cent of the chord back from the leading edge of the wing. The outer end was flush with the end of the wing. (Spoiler B, fig. 1.) Tests were made at 0° yaw with the spoiler and aileron deflected upward various amounts and at 20° yaw with the assumed maximum deflections for the various aileron movements given in Table V. The results of these tests are given in Table I. The rolling and yawing moment coefficients obtained with the spoiler up 60° and the aileron up various amounts are plotted in Figure 5 for five representative angles of attack. It will be noted that with the spoiler up 60°, increasing the upward aileron deflection beyond about 35°, decreased rather than increased the rolling-moment coefficient.

Tests were also made with the standard-size aileron directly behind a spoiler of the same size but with the spoiler hinged at the rear. (Spoiler C, fig. 1.) Inasmuch as the hinge moment of this type spoiler is used to reduce the control force required, a large moment was considered advantageous and a maximum spoiler deflection of 90° was assumed. The results of these tests are also given in Table I. The rolling and yawing moment coefficients with the spoiler up 90° and the aileron up various amounts are given in Figure 6. In this case the rolling moments are reduced by increasing the aileron deflection above a value of about 30°.

The effect of the rear-hinge spoiler in reducing the control force required was found by means of hinge-moment tests with the spoiler deflected alone, the aileron deflected alone, and both deflected in various combinations. The results of these tests are given in Table II. It may be seen that with the spoiler deflected, the hinge moments on the up aileron were considerably reduced.

The tests with spoilers B and C showed that with the spoiler up the assumed maximum amount, the maximum rolling moments, which were obtained with the ailerons about 30° to 35° up only, were not entirely satisfactory at angles of attack near the stall or above. It was apparent that with the ailerons directly behind the spoilers the combined effect was much less than the sum of the individual effects. As increasing the aileron deflection either upward or downward would not improve the control beyond the stall, it became necessary to increase the combined efficiency of the spoiler and aileron if satisfactory control were to be obtained. For an attempt in this direction it was decided to test a spoiler inboard of the aileron. The spoiler was made short and wide, 15 per cent of the wing chord by 10 per cent of the semispan, to make the moment arm as long as possible. As shown in Figure 2 (spoiler D), this was a rear-hinge spoiler with the axis located 20 per cent of the chord back of the leading edge of the wing. Preliminary tests were first made to find the best location of spoiler D along the span, the spoiler being deflected up 90° and the aileron up 60°. The results, which are given in Figure 7, showed that the best position was with the outboard end of the spoiler about 40 per cent of the semispan from the center of the wing.[1]

In order to determine the effect of changing the spoiler size, two additional sizes were tested at the best span locations, one having half the length and one two-thirds the width of spoiler D. The results of these tests, which are given in Figure 8, show that beyond the stall the spoiler size within the limits tested had little effect on the rolling moment; the one with the smallest chord (spoiler E) was adopted for the final tests with the standard-size ailerons. The complete results are given in Table I and the effect of deflecting the aileron upward with the spoiler up 90° is shown in Figure 9. With this combination it will be noted that the rolling moment increases with aileron deflection throughout the entire range tested.

Spoilers and short, wide ailerons.—The short, wide ailerons, 40 per cent of the chord by 30 per cent of the semispan, gave the best control moments at high angles of attack of the three sizes of ordinary ailerons tested under reference 1 but even they did not give entirely satisfactory values just at the stall. In an attempt to make the control satisfactory throughout the entire angle-of-attack range and at the same time to reduce the high control force required for these ailerons, they were tested in combination with two different rear-hinge spoilers. The first of these was the long, narrow spoiler C. (Fig. 2.) The results, which are given in Table III and Figure 10, show that although with the spoiler up 90° the rolling moment increases with upward aileron deflection throughout the entire range tested, the value is only slightly greater than that for the aileron alone.

As in the case of the standard ailerons, tests were next made with the short, wide spoiler D (fig. 2), at several locations along the span, the aileron being deflected upward 60°. The results of these tests, which are given in Figure 11, show that the best position is with the outboard end of the spoiler 50 per cent of the semispan from the center of the wing, leaving, as in the case of the standard-size ailerons, a gap of 20 per cent of the semispan between the aileron and spoiler.

The two smaller spoilers were also tested at the best location, but in this case the results (fig. 12) showed that the original size gave the highest rolling moments

[1] Further tests showed that the best spoiler location with the aileron neutral was with the outer edge 80 per cent of the semispan from the center of the wing. An exploration of the flow by means of threads showed that at relatively low angles of attack the air flow was burbled not only directly behind the spoiler but also over a considerable area on each side of it, including the outer 20 per cent of the wing.

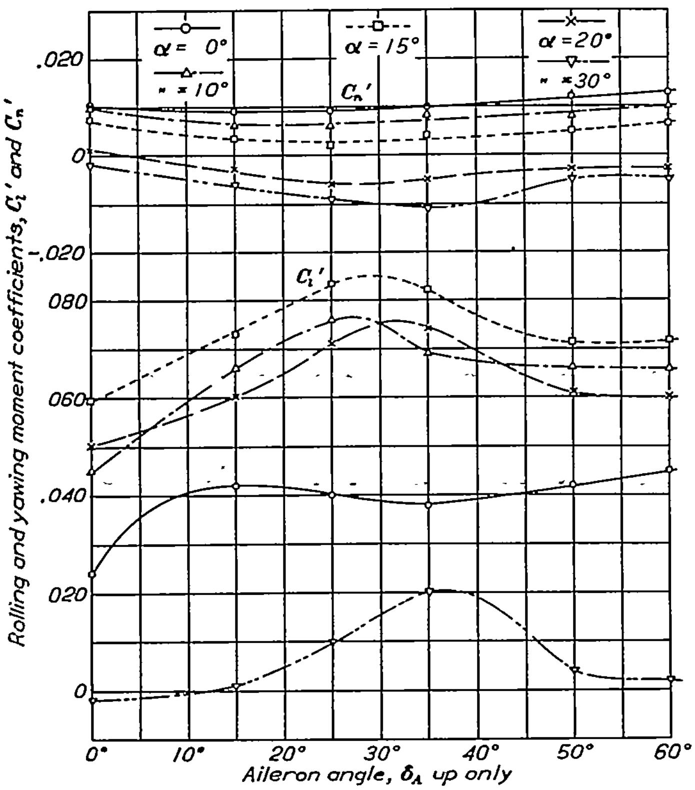

FIGURE 5.—Rolling and yawing moment coefficients due to spoiler B up 60° and standard ailerons

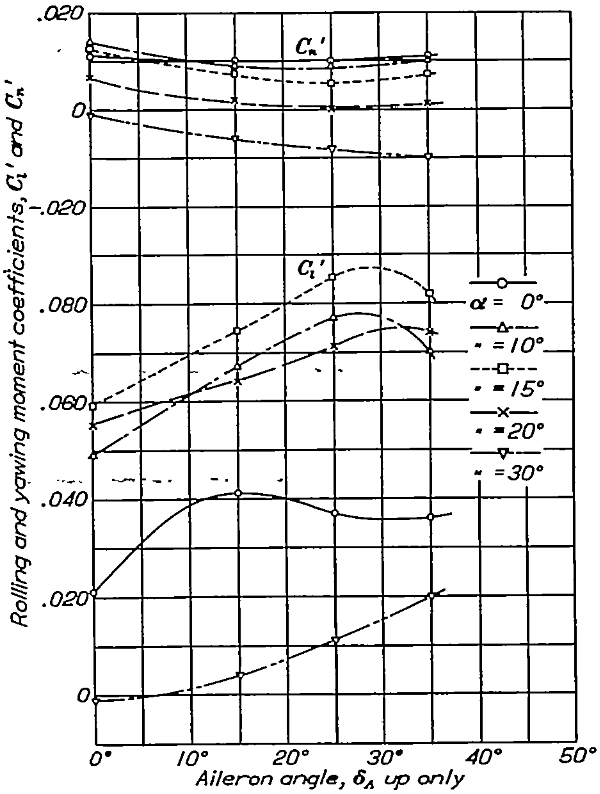

FIGURE 6.—Rolling and yawing moment coefficients due to spoiler C up 90° and standard ailerons

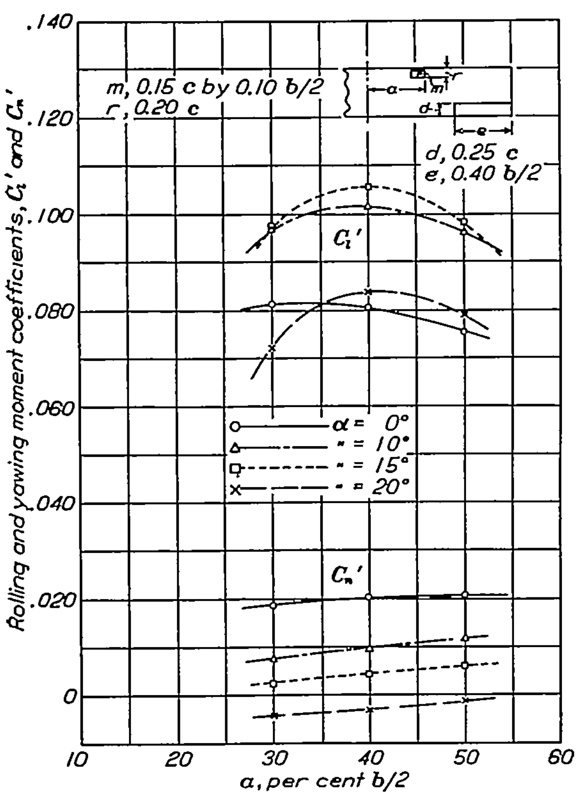

FIGURE 7.—Effect of span location of spoiler on rolling and yawing moment coefficients due to spoiler D and standard ailerons. δ_S=90°; δ_A=60° up only

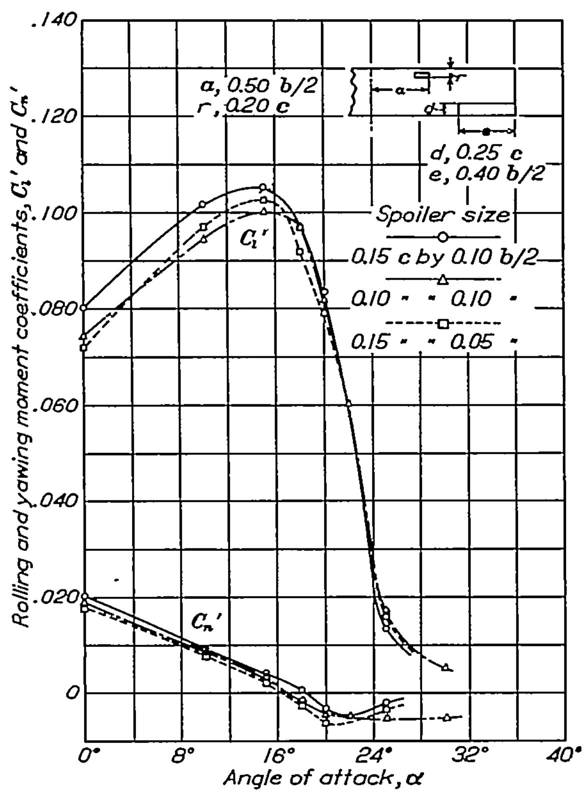

FIGURE 8.—Effect of spoiler size on rolling and yawing moment coefficients due to spoiler E and standard ailerons

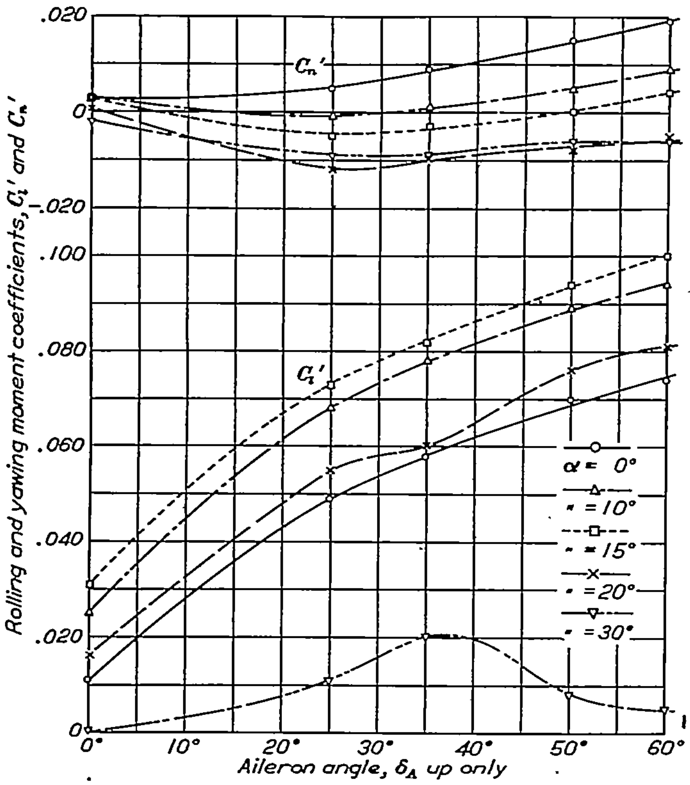

FIGURE 9.—Rolling and yawing moment coefficients due to spoiler E up 90° and standard ailerons

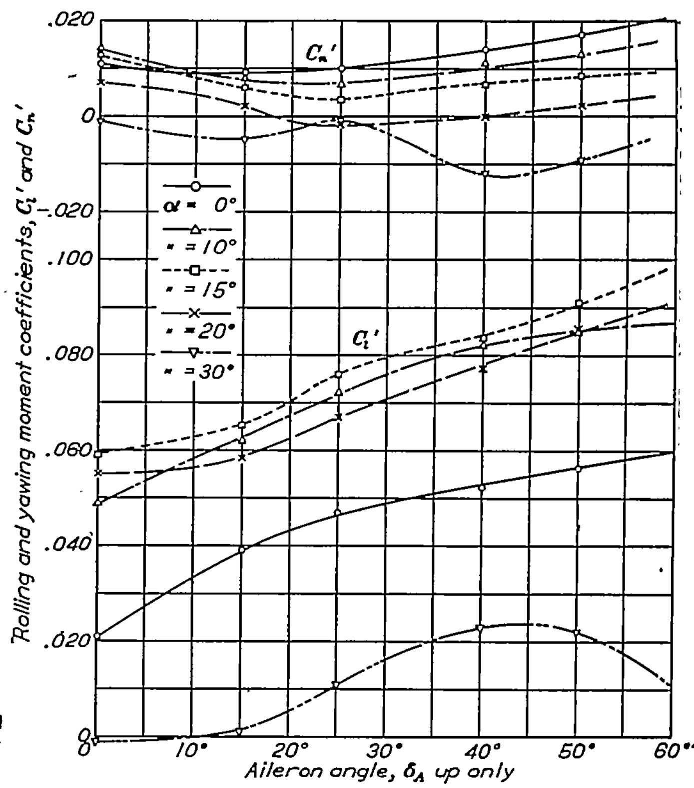

FIGURE 10.—Rolling and yawing moment coefficients due to spoiler C up 90° and short, wide ailerons

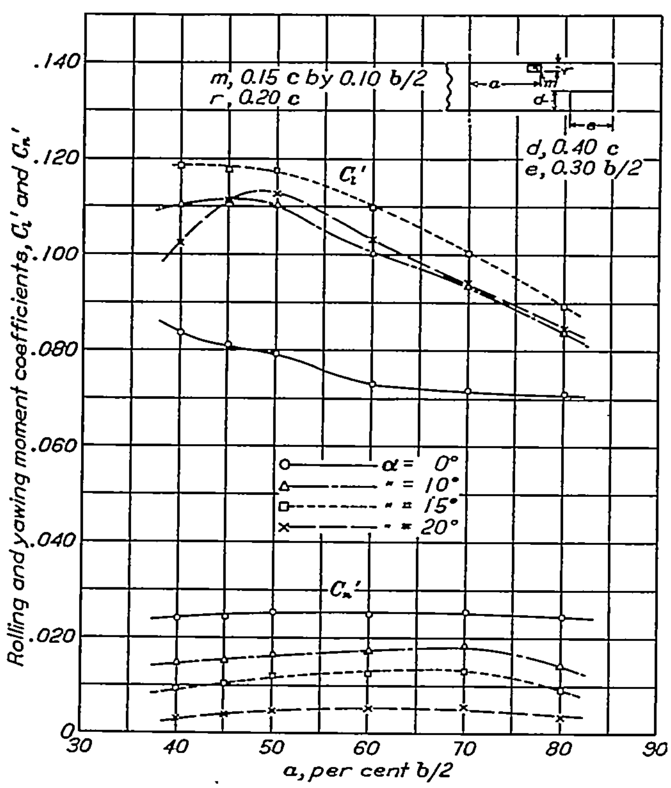

FIGURE 11.—Effect of span location of spoiler on rolling and yawing moment coefficients due to spoiler D and short, wide ailerons. $\delta_S=90°$; $\delta_A=60°$ up only

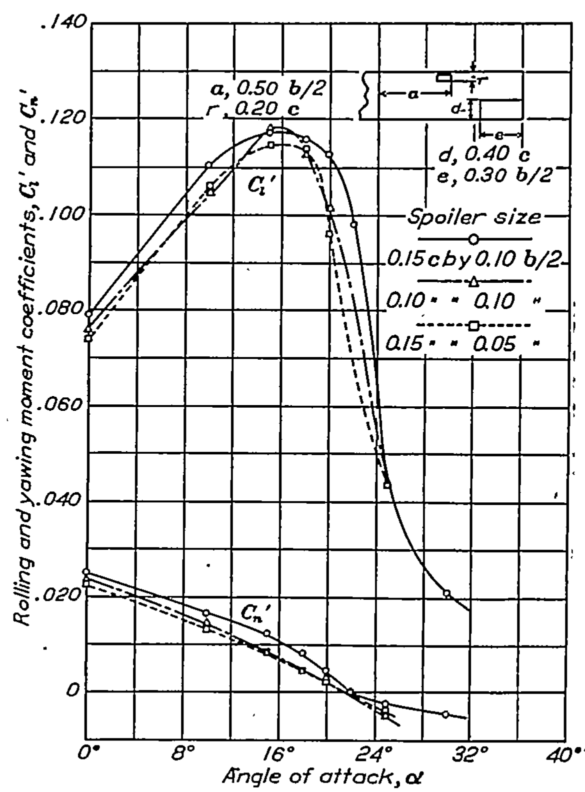

FIGURE 12.—Effect of spoiler size on rolling and yawing moment coefficients due to spoiler D and short, wide ailerons

at the high angles of attack, and as the extra hinge moment with the large size would be a help in reducing the control force required, it was adopted for the final tests, the results of which are given in Table IV. With this combination the interference between the spoiler and aileron was small.

DISCUSSION IN TERMS OF CRITERIONS

For a comparison of the different lateral control arrangements, the results of the tests are discussed in terms of criterions, which are explained in detail in reference 1 and briefly in the following paragraphs. By use of these criterions a comparison of the effect of the different control devices on the general performance, the lateral controllability, and the lateral stability may be made. The values of the criterions summarizing the results of the present tests are given in Table V, and the values for the standard and the short, wide ailerons alone are included for comparison.

GENERAL PERFORMANCE

The values of the three criterions used in connection with the general performance of the wing, the maximum lift coefficient, the speed-range ratio $\frac{C_{L max}}{C_{D min}}$ and the climb criterion $\frac{L}{D}$ at $C_L=0.70$ are not affected by the addition of a carefully installed spoiler, so these values are approximately the same for the various cases tested.

LATERAL CONTROLLABILITY

Rolling criterion.—The rolling criterion upon which the effectiveness of each of the aileron arrangements is judged is a figure of merit that is designed to be proportional to the initial acceleration of the wing tip that follows a deflection of the ailerons from neutral, regardless of the air speed or the plan form of the wing. Expressed in coefficient form for a rectangular monoplane wing, the criterion is

$$R\ C=\frac{C_l}{C_L}$$

where C_l is the rolling-moment coefficient about the body axis due to the lateral controls. The value of this expression that has been found to represent satisfactory control is approximately 0.075. A more detailed explanation of the derivation of $R\ C$ and of its more general form, which is applicable to any wing plan form, is given in reference 1.

The comparison of the lateral control devices covered by this report is given in Table V for the different aileron movements of reference 1, for four representative angles of attack: 0°, 10°, 20°, and 30°. The 0° angle represents the high-speed attitude; $\alpha=10°$ represents the highest angle of attack at which entirely satisfactory control with ordinary ailerons can be obtained; $\alpha=20°$ is the condition of greatest lateral instability and is probably about the greatest obtainable angle of attack in a steady glide with most present-day airplanes; and finally, $\alpha=30°$ is given only for a comparison with controls for possible future types of airplanes.

The large spoiler A when tested alone as a complete lateral control device, gave a lower value of $R\ C$ at an angle of attack of 0° than was obtained with the ordinary ailerons alone, but the value was nevertheless substantially greater than the assumed satisfactory one of 0.075. At $\alpha=10°$, the spoiler gave a slightly lower value of $R\ C$ than the assumed satisfactory one, but the control held reasonably close to the satisfactory value as the angle of attack was increased through 20°.

At $\alpha=0°$, all the ailerons, whether or not combined with spoilers, gave values of $R\ C$ greatly in excess of that considered necessary. Because the ailerons alone were designed to give approximately satisfactory control at an angle of attack of 10°, when combined with spoilers they gave in excess of the satisfactory value except for the case of the standard-size ailerons with upward movement only combined with long, narrow spoilers with which no increase of rolling moment was obtained by deflecting the aileron more than about 35°.

At $\alpha=20°$, which is definitely above the stall, the addition of any of the spoilers substantially increased the aileron control, the smallest effect being obtained with the short spoiler E with the standard ailerons and the greatest with the short spoiler D and the short, wide ailerons. The latter with the extreme differential movement gave 20 per cent greater than the assumed satisfactory value.

None of the combinations gave satisfactory control at an angle of attack of 30°.

Lateral control with sideslip.—If a wing is yawed appreciably, a rolling moment is set up that tends to raise the forward tip. The magnitude of this rolling moment is always greater at very high angles of attack than the available rolling moment due to ordinary ailerons. The highest angle of attack at which the aileron can balance the rolling moment due to 20° yaw is tabulated for all the arrangements tested as a criterion of control with sideslip. As previously mentioned, 20° yaw represents the conditions in a fairly severe sideslip. Table V shows that the lateral control against the effect of 20° sideslip is maintained up to approximately the same angle of attack with all of the combinations tested except one, that with the short, wide ailerons up 60° combined with spoiler D, which gave control to a substantially higher angle of attack.

Yawing moment due to ailerons and spoilers.—The desirable yawing moment due to ailerons depends to some extent upon the type of airplane that is being considered. For highly maneuverable military or

acrobatic machines complete independence of the controls as they affect turning moments about the various body axes is a desirable feature. On the other hand, for large transport airplanes or for machines to be operated by relatively inexperienced pilots, a favorable yawing moment of proper magnitude would be an appreciable aid to safe flying at high angles of attack. Finally, it is obvious that a yawing moment tending to turn the airplane out of its bank is never desirable under any circumstances.

Reference to Table V will show that spoiler A alone gives a favorable yawing moment about the body axes equal to about 1.5 times that produced by an average rudder at high speed (0.010) and about 4 times that produced by an average rudder at low speed (0.007).

Adding spoilers to standard ailerons reduced the adverse yawing moment considerably and in most cases eliminated it altogether for angles of attack up through 20°. A detailed comparison is most readily made by direct reference to Table V.

LATERAL STABILITY

Inasmuch as spoilers do not affect the lateral stability if they do not interrupt the wing surface when closed, the values of the criterions on this subject are considered the same as for the wings without spoilers. These values are given in Table V and explained in reference 1. The rolling moments tending to make the wings autorotate depend in a very critical manner on the exact profile of the airfoils and are sometimes quite different for two airfoils made to the same design. The two examples given in Table V represent the extremes of this variation.

CONTROL FORCE REQUIRED

The control-force criterion, with which the various lateral control devices are compared as regards control-stick force to attain assumed maximum deflections, is based on a stick movement of ±25° and is independent of air speed. The criterion is

$$CF=\frac{Fl}{qcS\,C_L}=\frac{C_H}{C_L}\left(\frac{\delta_A}{25}\right)$$

where F is the force applied at end of control lever of length l and $\frac{\delta_A}{25}$ is the gear ratio between the aileron and the control lever.

The control-force criterions have been computed for spoiler A alone and for various combinations of spoilers and ailerons. They are given in Table V, together with criterions for the two ailerons tested alone. The hinge moments were measured for spoilers A and C, and approximate values were computed for spoilers B, D, and E based on the assumption that the moments were proportional to the span and the square of the chord of the spoilers.

The control force required for spoiler A alone was definitely lower than that for the ordinary ailerons tested (about one-third that for the standard ailerons with equal up-and-down deflection). The spoiler tends to float with a small deflection, however, and would require a special linkage or spring installation for satisfactory operation.

Interconnecting a spoiler with the ailerons reduced the control force in every case. With spoiler C and standard ailerons with average differential or up-only arrangement, the control force was slightly negative; that is, the air force on the control system was such as to hold the controls in a deflected state. This condition indicates that by choosing the proper relative sizes, locations, and linkages of the ailerons and spoilers, any desired amount of control force could be obtained.

OPTIMUM COMBINATIONS

For a nonacrobatic airplane that requires only a moderate degree of lateral control it seems likely that spoiler A used alone should provide a reasonably satisfactory control superior in every way to that provided by conventional flap-type ailerons. Reasonably high values of $R\,C$ are maintained up to angles of attack beyond the range which can be maintained by average airplanes, the yawing moments are in a favorable sense throughout the entire range, and the control force required is very small. The results, although they indicate that it would be difficult to obtain a substantial increase in control by increasing the size of the spoiler, are sufficiently favorable to justify further tests on an airplane in flight.

A substantial improvement was made in the performance of the standard-size ailerons with each of the spoilers tested, but none gave entirely satisfactory control. Inasmuch as the front-hinge type substantially decreases the control force required, the optimum combination with the standard-size aileron is probably the long spoiler B with average differential aileron movement.

The short, wide ailerons in combination with the short spoiler D gave the highest values of $R\,C$ at the high angles of attack as well as the highest favorable yawing moments. If, as seems likely, the control force can be reduced to any value desired by the proper selection of the relative sizes and deflections, and if the rear-hinge spoiler can be made to operate satisfactorily in flight, this combination should be very good for an airplane requiring great maneuverability.

CONCLUSIONS

1. In the combined action of spoilers and ailerons the full effects of both are not obtained if the spoilers are located directly ahead of the ailerons.

2. With the proper combination of spoilers and ordinary ailerons it is possible to obtain satisfactory

rolling control up to high angles of attack, accompanied by favorable yawing moments and small control forces.

3. It is possible to obtain a moderate amount of rolling control together with favorable yawing moments and small control forces by means of a spoiler alone.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *June 13, 1932.*

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149900—33——47

TABLE I

FORCE TESTS. 10 BY 60 INCH CLARK Y WING WITH PLAIN AILERONS 25 PER CENT c BY 40 PER CENT $b/2$ AND VARIOUS SPOILERS. R. N.=609,000. VELOCITY=80 M. P. H.

(CONTROLS NEUTRAL)

α	−5°	−4°	−3°	0°	5°	10°	14°	15°	16°	18°	20°	22°	25°	30°	40°	50°	60°
YAW=0°																	
C_L	−0.015	0.059	0.131	0.334	0.703	1.045	1.245	1.268	1.277	1.263	1.170	1.087	0.870	0.820	0.790	0.705	0.598
C_D	.017	.016	.016	.020	.045	.085	.127	.139	.154	.193	.234	.284	.396	.518	.703	.870	1.037
YAW=−20°																	
C_L	−0.020	--------	0.110	0.290	0.625	0.923	1.105	--------	--------	1.177	1.170	1.150	1.012	0.890	0.811	0.750	0.641
C_D	.019	--------	.018	.021	.041	.077	.112	--------	--------	.161	.209	.262	.412	.511	.678	.868	1.040
C_l'	−.002	--------	−.003	−.004	−.007	−.011	−.017	--------	--------	−.047	−.074	−.093	−.121	−.095	−.056	−.048	−.044
C_n'	.002	--------	.001	.001	.002	.005	.008	--------	--------	.014	.017	.022	.023	.050	.043	.047	.055

CONTROLS DEFLECTED

SPOILER A

10 per cent c by 60 per cent $b/2$ front hinge

(AILERONS NEUTRAL)

δ_S	α	0°	10°	14°	16°	18°	20°	22°	25°	30°	40°
°		YAW=0°									
10	C_l'	0.006	0.011	0.030	0.033	----------	0.018	0.002	----------	−0.002	0.002
10	C_n'	.001	.002	.003	.002	----------	−.001	0	----------	−.002	−.002
20	C_l'	.020	.046	.052	.053	----------	.044	.027	----------	0	.002
20	C_n'	.007	.006	.004	.003	----------	−.003	−.006	----------	−.002	−.002
40	C_l'	.036	.065	.073	----------	0.073	.065	.045	−0.002	−.003	.001
40	C_n'	.012	.011	.008	----------	.005	.001	−.002	−.002	−.001	−.001
60	C_l'	.043	.075	.081	----------	.082	.077	.058	.005	−.001	0
60	C_n'	.015	.015	.013	----------	.009	.006	.003	−.002	−.001	−.002
90	C_l'	.045	.078	.085	----------	.078	.077	.063	.007	−.002	.001
90	C_n'	.017	.018	.016	----------	.013	.010	.007	.004	−.001	−.002
		YAW=−20°									
60	C_l'	0.016	0.046	0.059	----------	0.086	0.095	0.088	0.056	0.026	−0.001
60	C_n'	.016	.018	.016	----------	.011	.007	.005	.011	−.008	.002

SPOILER B

7 per cent c by 40 per cent $b/2$ front hinge

δ_S	δ_A up	α	0°	10°	14°	16°	18°	20°	22°	25°	30°	40°
°	°		YAW=0°									
10	0	C_l'	0.006	0.006	0.006	----------	0.005	0.009	0.003	−0.021	0.002	0.002
10	0	C_n'	0	0	−.001	----------	−.001	−.001	−.002	−.002	−.002	−.002
60	0	C_l'	.024	.052	.059	0.060	.059	.051	.041	−.007	−.002	.001
60	0	C_n'	.010	.010	.008	.007	.005	.001	.001	−.007	−.002	−.002
10	10	C_l'	.023	.024	.023	.021	.017	.007	.003	−.017	.003	.004
10	10	C_n'	0	−.004	−.005	−.005	−.005	−.006	−.005	−.006	−.004	−.005
20	10	C_l'	.024	.033	.039	.040	.042	.037	.020	−.003	.003	.013
20	10	C_n'	.001	0	−.001	−.002	−.004	−.006	−.006	−.004	−.006	−.005
20	20	C_l'	.035	.048	.052	.052	.049	.039	.022	.003	.007	.018
20	20	C_n'	.003	−.002	−.003	−.004	−.006	−.009	−.009	−.007	−.007	−.008
20	40	C_l'	.048	.057	.061	.060	.059	.049	.033	.003	.015	.023
20	40	C_n'	.008	.002	−.002	−.003	−.005	−.008	−.008	−.009	−.008	−.014
20	60	C_l'	.059	.070	.074	.072	.068	.058	.042	.007	.003	.009
20	60	C_n'	.014	.006	.003	0	−.002	−.005	−.006	−.008	−.006	−.008
40	10	C_l'	.030	.049	.057	.057	.055	.048	.035	−.012	.001	.003
40	10	C_n'	.006	.004	.002	.001	−.001	−.005	−.007	−.010	−.004	−.005
40	20	C_l'	.037	.061	.066	.066	.063	.055	.038	−.006	.006	.008
40	20	C_n'	.006	.003	.001	−.001	−.004	−.007	−.008	−.012	−.007	−.008
40	25	C_l'	.036	.063	.069	.069	.066	.057	.040	.009	.010	.011
40	25	C_n'	.006	.003	0	−.002	−.004	−.007	−.009	−.009	−.008	−.010
40	40	C_l'	.040	.062	.068	.068	.064	.057	.043	.007	.016	.024
40	40	C_n'	.009	.006	.003	.002	−.001	−.005	−.007	−.005	−.008	−.014
60	15	C_l'	042	066	.072	.074	.071	.060	.041	.012	.001	.003
60	15	C_n'	.009	.006	.004	.003	0	−.003	−.006	−.009	−.006	−.007
60	25	C_l'	.040	.076	.083	.084	.081	.071	.056	.022	.010	.011
60	25	C_n'	.009	.006	.003	.001	−.002	−.006	−.008	−.011	−.009	−.011
60	35	C_l'	.038	.069	.080	.084	.083	.074	.061	.023	.020	.020
60	35	C_n'	.010	.008	.006	.002	−.001	−.005	−.008	−.013	−.011	−.013
60	50	C_l'	.042	.066	.071	.072	.070	.061	.047	.002	.004	.012
60	50	C_n'	.012	.008	.006	.004	.001	−.003	−.005	−.008	−.005	−.008
60	60	C_l'	.045	.066	.072	.072	.070	.060	.046	.002	.002	.009
60	60	C_n'	.013	.010	.007	.006	.002	−.003	−.006	−.009	−.005	−.008
			YAW=−20°									
20	60	C_l'	0.064	0.074	0.076	0.079	0.082	0.083	0.091	0.073	0.052	0.014
20	60	C_n'	.016	.008	.004	.003	0	−.003	−.007	−.011	−.025	−.009
40	25	C_l'	.042	.052	.056	.060	.063	.065	.060	.047	.056	.003
40	25	C_n'	.007	.003	.001	−.001	−.003	−.003	−.005	−.006	−.030	−.007
60	25	C_l'	.042	.055	.060	.068	.076	.081	.075	.055	.061	.001
60	25	C_n'	.010	.006	.004	.002	0	−.003	−.003	−.003	−.031	−.007

TABLE I—Continued

FORCE TESTS. 10 BY 60 INCH CLARK Y WING WITH PLAIN AILERONS 25 PER CENT c BY 40 PER CENT $b/2$ AND VARIOUS SPOILERS. R. N.=609,000. VELOCITY=80 M. P. H.

SPOILER C

7 per cent c by 40 per cent $b/2$ rear hinge

α			0°	10°	14°	16°	18°	20°	22°	25°	30°	40°
δ_S	δ_A up		YAW=0°									
°	°											
10	0	C_l'	0.006	0.009	0.016	0.026	0.039	0.040	0.028	0	0	0.001
10	0	C_n'	.001	.001	.003	.007	.007	.004	.002	−.001	−.001	−.001
40	0	C_l'	.008	.039	.051	.054	.053	.052	.051	.003	−.002	.002
40	0	C_n'	.006	.013	.012	.012	.011	.010	.007	0	−.001	−.002
90	0	C_l'	.021	.049	.058	.060	.059	.055	.046	.010	−.001	0
90	0	C_n'	.011	.014	.013	.012	.010	.007	.004	0	−.001	−.002
10	10	C_l'	.023	.027	.033	.038	.043	.045	.035	−.013	.003	.003
10	10	C_n'	.001	−.002	−.007	.003	.003	.001	−.002	−.004	−.004	−.005
20	10	C_l'	.025	.037	.044	.047	.051	.048	.040	.002	.002	.004
20	10	C_n'	.002	.004	.006	.006	.005	.002	0	−.003	−.004	−.005
20	20	C_l'	.035	.053	.058	.060	.060	.053	.043	.010	.007	.008
20	20	C_n'	.004	.003	.003	.003	.002	0	−.002	−.006	−.007	−.008
20	40	C_l'	.051	.057	.064	.063	.063	.056	.046	.012	.017	.024
20	40	C_n'	.009	.006	.004	.004	.003	.001	−.001	−.005	−.008	−.014
40	10	C_l'	.024	.051	.060	.063	.061	.058	.053	.007	0	.003
40	10	C_n'	.006	.009	.009	.008	.007	.007	.004	−.003	−.004	−.005
40	20	C_l'	.029	.064	.071	.074	.070	.064	.058	.013	.005	.008
40	20	C_n'	.006	.007	.006	.005	.004	.003	.002	−.005	−.007	−.009
40	30	C_l'	.033	.063	.075	.078	.077	.072	.062	.021	.015	.015
40	30	C_n'	.008	.008	.007	.006	.003	.002	.002	−.007	−.008	−.012
40	40	C_l'	.039	.062	.071	.074	.069	.066	.060	.016	.017	.023
40	40	C_n'	.010	.010	.008	.007	.006	.005	.004	−.003	−.007	−.014
60	30	C_l'	.034	.069	.081	.085	.084	.073	.065	.026	.015	.016
60	30	C_n'	.010	.010	.008	.006	.004	.001	.001	−.008	−.009	−.012
90	15	C_l'	.041	.067	.074	.075	.070	.064	.054	.025	.004	.006
90	15	C_n'	.010	.009	.008	.007	.005	.002	0	−.005	−.006	−.007
90	25	C_l'	.037	.077	.085	.086	.081	.071	.060	.032	.011	.011
90	25	C_n'	.010	.009	.006	.005	.003	0	−.002	−.007	−.008	−.010
90	35	C_l'	.036	.070	.080	.084	.081	.074	.065	.035	.020	.020
90	35	C_n'	.011	.010	.008	.007	.004	.001	−.002	−.007	−.010	−.013
			YAW=−20°									
40	25	C_l'	0.041	0.052	0.058	0.061	0.068	0.071	0.063	0.044	0.017	0.004
40	25	C_n'	.008	.006	.005	.005	.004	.004	.005	−.010	−.012	−.005
90	25	C_l'	.040	.055	.062	.069	.077	.060	.053	.053	.026	.003
90	25	C_n'	.011	.010	.008	.007	.006	.004	−.004	−.009	−.013	−.005

SPOILER E

10 per cent c by 10 per cent $b/2$ rear hinge

α				0°	10°	15°	18°	20°	22°	25°	30°	40°
δ_S	δ_A up	δ_A down		YAW=0°								
°	°	°										
15	10	0	C_l'	0.022	0.030	0.044	0.040	0.029	0.009	0.006	0.002	0.004
15	10	0	C_n'	0	−.002	−.002	−.004	−.006	−.006	−.004	−.005	−.006
30	10	0	C_l'	.021	.041	.045	.041	.030	.033	.007	.002	.003
30	10	0	C_n'	0	−.001	−.002	−.004	−.006	−.005	−.005	−.005	−.006
30	20	0	C_l'	.037	.058	.065	.059	.046	.039	.012	.008	.007
30	20	0	C_n'	.002	−.003	−.005	−.008	−.010	−.004	−.008	−.007	−.009
45	10	0	C_l'	.023	.042	.046	.042	.027	.039	.007	.001	.003
45	10	0	C_n'	.001	−.001	−.002	−.004	−.007	−.001	−.006	−.005	−.005
45	20	0	C_l'	.039	.060	.065	.059	.044	.043	.013	.009	.008
45	20	0	C_n'	.003	−.002	−.005	−.007	−.008	−.003	−.008	−.007	−.009
45	30	0	C_l'	.049	.072	.078	.073	.057	.050	.020	.016	.015
45	30	0	C_n'	.006	0	−.005	−.008	−.010	−.006	−.010	−.010	−.012
55	20	0	C_l'	.040	.063	.066	.061	.044	.041	.012	.009	.007
55	20	0	C_n'	.003	−.002	−.005	−.007	−.008	−.004	−.008	−.007	−.008
55	30	0	C_l'	.050	.073	.077	.074	.058	.050	.020	.015	.014
55	30	0	C_n'	.006	0	−.004	−.007	−.009	−.007	−.010	−.009	−.012
90	25	0	C_l'	.049	.068	.073	.070	.055	.037	.016	.011	.011
90	25	0	C_n'	.005	−.001	−.005	−.009	−.012	−.009	−.009	−.009	−.010
90	35	0	C_l'	.058	.078	.082	.077	.060	.044	.019	.020	.019
90	35	0	C_n'	.009	.001	−.003	−.007	−.010	−.008	−.008	−.009	−.013
90	50	0	C_l'	.070	.089	.094	.090	.076	.054	.015	.008	.012
90	50	0	C_n'	.015	.005	0	−.004	−.008	−.007	−.005	−.006	−.008
90	60	0	C_l'	.074	.094	.100	.097	.081	.060	.017	.005	.010
90	60	0	C_n'	.019	.009	.004	−.002	−.006	−.005	−.005	−.006	−.008
90	0	0	C_l'	.011	.025	.031	.028	.016	.007	.003	0	.001
90	0	0	C_n'	.003	.003	.003	.002	.001	0	−.002	−.002	−.002
				YAW=−20°								
90	25	25	C_l'	0.073	0.077	0.083	0.087	0.079	0.049	0.050	0.021	0.004
90	25	25	C_n'	−.004	−.014	−.020	−.020	−.021	−.029	−.036	−.034	−.016
90	35	15	C_l'	.075	.081	.085	.093	.087	.054	.061	.035	.010
90	35	15	C_n'	.005	−.005	−.012	−.014	−.015	−.023	−.035	−.035	−.014
90	50	7	C_l'	.071	.084	.090	.097	.096	.063	.070	.043	.018
90	50	7	C_n'	.012	.003	−.003	−.007	−.009	−.015	−.029	−.030	−.011
90	60	0	C_l'	.066	.082	.089	.010	.099	.063	.070	.048	.013
90	60	0	C_n'	.017	.009	.003	−.001	−.003	−.010	−.024	−.025	−.008

TABLE II

HINGE-MOMENT COEFFICIENT, C_H

SPOILER A

(0.10 c by 0.60 $b/2$ front hinge)

δ_S / α	0°	5°	10°	20°	30°	40°	50°	60°	80°
0°	−0.0001	0.0002	0.0003	0.0004	0.0006	0.0009	0.0010	0.0012	0.0014
10°	−.0002	.0001	.0001	.0003	.0005	.0007	.0010	.0011	.0013
15°	−.0003	−.0001	0	.0002	.0004	.0007	.0008	.0010	.0011
20°	−.0001	−.0001	0	.0002	.0004	.0006	.0008	.0010	.0012

SPOILER C

(0.07 c by 0.40 $b/2$ rear hinge)

δ_S / α	[a] 0°	[b] 0°	10°	20°	30°	40°	60°	80°	90°	100°	110°	120
0°	0	----------	−0.0008	−0.0008	−0.0007	−0.0006	−0.0006	−0.0006	−0.0006	−0.0006	−0.0006	−0.0005
10°	0	−0.0006	−.0006	−.0005	−.0005	−.0005	−.0005	−.0005	−.0005	−.0006	−.0005	−.0005
20°	−.0001	−.0006	−.0005	−.0004	−.0004	−.0004	−.0005	−.0005	−.0005	−.0004	−.0004	−.0001

STANDARD AILERON

(0.25 c by 0.40 $b/2$)

	Down aileron					Up aileron						
δ_A / α	25°	20°	15°	5°	0°	−5°	−10°	−15°	−20°	−25°	−30°	−35°
0°	−0.0033	−0.0027	−0.0019	−0.0009	−0.0006	0	0.0003	0.0007	0.0012	0.0018	0.0025	0.0034
10°	−.0041	−.0034	−.0027	−.0016	−.0008	−.0005	----------	.0004	----------	.0017	.0024	.0031
20°	----------	−.0043	−.0040	−.0032	−.0025	−.0019	----------	−.0004	----------	.0006	.0017	.0020

STANDARD AILERON AND SPOILER C

Spoiler up 90°, aileron variable

	Up aileron								Spoiler
δ_A / α	0°	−5°	−10°	−15°	−20°	−25°	−30°	−35°	δ_S=90°
0°	−0.0011	−0.0008	−0.0003	−0.0001	----------	0	0.0002	0.0004	−0.0006
10°	----------	----------	−.0011	----------	−0.0003	0	.0004	.0004	−.0006
20°	----------	----------	−.0013	----------	−.0005	−.0003	−.0001	.0003	−.0005

[a] Opening moment.

[b] Moment required to close.

TABLE III

FORCE TESTS. 10 BY 60 INCH CLARK Y WING WITH PLAIN AILERONS 40 PER CENT c BY 30 PER CENT $b/2$ AND REAR-HINGE SPOILER 7 PER CENT c BY 40 PER CENT $b/2$. R. N.=609,000. VELOCITY=80 M. P. H.

(CONTROLS NEUTRAL)

α	−5°	−4°	−3°	0°	5°	10°	14°	15°	16°	18°	20°	22°	25°	30°	40°	50°	60°
YAW=0°																	
C_L	−0.020	0.047	0.120	0.330	0.602	1.025	1.205	1.208	1.196	1.185	1.130	1.055	0.840	0.855	0.810	0.685	0.592
C_D	.017	.016	.017	.021	.044	.084	.127	.145	.162	.195	.239	.282	.413	.533	.718	.860	1.017
YAW=−20°																	
C_L	--------	--------	.105	.284	--------	.913	1.077	--------	1.110	1.130	1.135	.933	.905	.887	.800	.750	.632
C_D	--------	--------	.017	.020	--------	.075	.110	--------	.131	.168	.216	.346	.408	.505	.663	.857	1.018
C_l'	--------	--------	−.001	−.003	--------	−.011	−.019	--------	−.033	−.056	−.076	−.096	−.105	−.092	−.055	−.046	−.043
C_n'	--------	--------	.002	.002	--------	.005	.008	--------	.011	.015	.019	.026	.039	.049	.043	.046	.053

(CONTROLS DEFLECTED)

α			0°	10°	14°	16°	18°	20°	22°	25°	30°	40°
δ_S	δ_A up		YAW=0°									
°	°											
10	10	C_l'	0.025	0.027	0.030	0.032	0.037	0.040	0.027	−0.009	−0.010	0.002
10	10	C_n'	.001	−.003	−.002	.001	.002	0	−.002	−.004	−.002	−.005
20	10	C_l'	.026	.035	.040	.041	.047	.046	.039	0	−.009	.002
20	10	C_n'	.002	.003	.004	.004	.004	.001	−.002	−.004	−.002	−.006
20	20	C_l'	.041	.052	.056	.055	.056	.052	.041	.007	−.001	.005
20	20	C_n'	.004	.002	.001	.001	0	−.002	−.003	−.007	−.006	−.008
20	45	C_l'	.066	.082	.087	.084	.084	.080	.067	.028	.018	.023
20	45	C_n'	.017	.011	.007	.005	.002	−.001	−.003	−.006	−.009	−.015
40	10	C_l'	.027	.048	.056	.054	.056	.053	.044	.010	−.004	.002
40	10	C_n'	.005	.007	.007	.006	.005	.003	0	−.004	−.003	−.006
40	20	C_l'	.042	.063	.068	.065	.064	.059	.048	.015	.005	.005
40	20	C_n'	.005	.004	.003	.002	0	−.002	−.002	−.006	−.007	−.008
40	40	C_l'	.057	.084	.087	.083	.083	.076	.062	.024	.021	.019
40	40	C_n'	.015	.010	.007	.005	.002	0	−.003	−.006	−.012	−.014
90	15	C_l'	.039	.062	.066	.064	.063	.058	.048	.016	.001	.003
90	15	C_n'	.009	.008	.007	.006	.004	.002	0	−.006	−.005	−.007
90	25	C_l'	.047	.072	.077	.075	.076	.067	.054	.021	.011	.008
90	25	C_n'	.010	.007	.005	.002	.001	−.002	−.003	−.007	−.001	−.010
90	40	C_l'	.052	.082	.085	.082	.082	.077	.063	.027	.023	.019
90	40	C_n'	.014	.011	.008	.005	.003	0	−.003	−.007	−.012	−.014
90	50	C_l'	.056	.085	.092	.090	.090	.085	.070	.029	.022	.026
90	50	C_n'	.017	.013	.010	.007	.005	.002	−.001	−.004	−.009	−.015
90	0	C_l'	.021	.049	.058	.060	.069	.055	.046	.010	−.001	0
90	0	C_n'	.011	.014	.013	.012	.010	.007	.004	0	−.001	−.002
			YAW=−20°									
20	45	C_l'	0.072	0.090	0.094	0.097	0.104	0.104	0.091	0.077	0.061	0.021
20	45	C_n'	.021	.011	.006	.004	.001	−.002	−.016	−.020	−.030	−.020
40	40	C_l'	.071	.087	.093	.096	.100	.102	.087	.068	.067	.016
40	40	C_n'	.021	.011	.007	.005	.002	−.002	−.016	−.016	−.027	−.018
90	40	C_l'	.073	.088	.093	.097	.102	.104	.091	.076	.057	.013
90	40	C_n'	.024	.014	.009	.007	.004	0	−.016	−.021	−.026	−.017

TABLE IV

FORCE TESTS. 10 BY 60 INCH CLARK Y WING WITH PLAIN AILERONS 40 PER CENT c BY 30 PER CENT $b/2$ AND REAR-HINGE SPOILER 15 PER CENT c BY 10 PER CENT $b/2$. R. N.=609,000. VELOCITY=80 M. P. H.

(CONTROLS NEUTRAL)

α	−5°	−4°	−3°	0°	5°	10°	12°	14°	15°	18°	20°	22°	25°	30°	40°	50°	60°
								YAW=0°									
C_L	−0.004	0.063	0.142	0.354	0.718	1.050	1.163	1.240	1.270	1.225	1.185	1.118	0.790	0.860	0.800	0.710	0.600
C_D	.017	.016	.017	.022	.047	.089	.110	.130	.144	.199	.239	.283	.418	.538	.713	.878	1.037
								YAW=−20°									
C_L	0.006	--------	--------	0.304	0.633	0.941	--------	1.099	--------	1.167	1.170	1.145	0.918	0.915	0.805	0.758	0.642
C_D	.020	--------	--------	.024	.044	.081	--------	.116	--------	.162	.212	.259	.411	.528	.675	.876	1.010
C_l'	−.003	--------	--------	−.006	−.008	−.013	--------	−.022	--------	−.051	−.075	−.091	−.107	−.094	−.055	−.047	−.044
C_n'	.002	--------	--------	.001	.002	.005	--------	.008	--------	.015	.018	.024	.038	.049	.043	.044	.053

(CONTROLS DEFLECTED)

α				0°	10°	15°	18°	20°	22°	25°	30°	40°
δ_S	δ_A up	δ_A down						Yaw=0°				
°	°	°										
15	10	0	C_l'	0.023	0.043	0.050	0.045	0.043	0.028	−0.001	−0.001	0.003
15	10	0	C_n'	0	0	−.001	−.002	−.004	−.010	−.004	−.004	−.006
30	10	0	C_l'	.024	.050	.055	.050	.045	.028	−.004	.002	.002
30	10	0	C_n'	.001	.001	−.001	−.002	−.004	−.005	−.003	−.004	−.006
30	20	0	C_l'	.041	.069	.075	.070	.064	.046	.001	.005	.006
30	20	0	C_n'	.003	0	−.004	−.006	−.009	−.010	−.007	−.007	−.009
45	10	0	C_l'	.024	.055	.058	.052	.044	.029	−.005	.001	.002
45	10	0	C_n'	.002	.001	−.001	−.002	−.004	−.005	−.002	−.004	−.006
45	20	0	C_l'	.042	.073	.078	.070	.056	.046	0	.005	.006
45	20	0	C_n'	.004	0	−.004	−.006	−.008	−.011	−.006	−.007	−.009
45	30	0	C_l'	.053	.092	.096	.089	.080	.066	.012	.013	.013
45	30	0	C_n'	.009	.002	−.004	−.006	−.010	−.013	−.009	−.009	−.012
55	20	0	C_l'	.047	.075	.079	.070	.057	.047	0	.007	.006
55	20	0	C_n'	.005	0	−.003	−.005	−.008	−.010	−.006	−.007	−.009
55	30	0	C_l'	.058	.092	.097	.091	.076	.066	.010	.014	.012
55	30	0	C_n'	.011	.002	−.003	−.006	−.010	−.013	−.009	−.009	−.013
90	25	25	C_l'	.096	.114	.113	.095	.070	.051	.003	.009	.007
90	25	25	C_n'	−.003	−.016	−.022	−.023	−.023	−.021	−.018	−.020	−.024
90	35	15	C_l'	.094	.122	.122	.101	.084	.070	.021	.017	.016
90	35	15	C_n'	.009	−.005	−.011	−.014	−.016	−.019	−.017	−.017	−.022
90	50	7	C_l'	.093	.117	.126	.117	.112	.093	.038	.018	.027
90	50	7	C_n'	.020	.010	.003	−.002	−.005	−.009	−.010	−.010	−.020
90	60	0	C_l'	.079	.110	.117	.116	.113	.098	.044	.021	.020
90	60	0	C_n'	.025	.016	.012	.008	.004	0	−.003	−.005	−.011
90	0	0	C_l'	.020	.036	.037	.032	.030	----------	−.004	----------	----------
90	0	0	C_n'	.005	.005	.006	.006	.005	----------	.002	----------	----------
								YAW=−20°				
90	25	25	C_l'	.084	.094	.100	.099	.095	.050	.051	.033	.001
90	25	25	C_n'	−.002	−.018	−.024	−.023	−.022	−.033	−.037	−.038	−.022
90	35	15	C_l'	.093	.102	.105	.111	.108	.071	.067	.051	.010
90	35	15	C_n'	.012	−.004	−.012	−.015	−.016	−.030	−.035	−.039	−.023
90	50	7	C_l'	.084	.121	.129	.142	.137	.107	.096	.078	.026
90	50	7	C_n'	.023	.017	.006	0	−.002	−.020	−.027	−.036	−.024
90	60	0	C_l'	.071	.103	.134	.148	.148	.123	.109	.095	.039
90	60	0	C_n'	.027	.023	.021	.013	.009	−.010	−.016	−.029	−.022

TABLE V

CRITERIONS SHOWING RELATIVE MERITS OF SPOILER AND AILERON COMBINATIONS

Subject	Criterion	Spoiler A	Standard ailerons[a]				Standard ailerons and Spoiler B			Standard ailerons and Spoiler C		
		$\delta_S=60°$	Standard, 25° up, 25° down	Differential, No. 1, 35° up, 15° down	Differential No. 2, 50° up, 7° down	Up only, 60°	Standard, $\delta_A=\begin{cases}25° \text{ up}\\25° \text{ down}\end{cases}$ $\delta_S=60°$	Differential No. 1, $\delta_A=\begin{cases}35° \text{ up,}\\15° \text{ down}\end{cases}$ $\delta_S=60°$	Up only, $\delta_A=35°$ $\delta_S=60°$	Standard, $\delta_A=\begin{cases}25° \text{ up}\\25° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 1, $\delta_A=\begin{cases}35° \text{ up,}\\15° \text{ down}\end{cases}$ $\delta_S=90°$	Up only, $\delta_A=30°$, $\delta_S=90°$
Wing area or minimum speed	$C_{L_{max}}$, $\delta=0°$	1.277	1.270	1.270	1.270	1.270	1.277	1.277	1.277	1.277	1.277	1.277
Speed range	$\frac{C_{L_{max}}}{C_{D_{min}}}$, $\delta=0°$	81.0	79.4	79.4	79.4	79.4	81.0	81.0	81.0	81.0	81.0	81.0
Rate of climb	L/D at $C_L=0.70$, $\delta=0°$	15.6	15.9	15.9	15.9	15.9	15.6	15.6	15.6	15.6	15.6	15.6
Lateral controllability	RC $\alpha=0°$	.130	.204	.202	.214	.196	.219	.186	.114	.214	.182	.110
	RC $\alpha=10°$	.069	.076	.074	.074	.072	.105	.087	.064	.105	.087	.070
	RC $\alpha=20°$	.060	[b].038	[b].051	[b].055	[b].054	.063	.067	.061	.062	.064	.059
	RC $\alpha=30°$	0	.017	.005	.002	.002	.008	.020	.028	.006	.019	.021
Lateral control with sideslip.	Maximum α at which controls will balance C_l' due to 20° yaw.	22°	20°	20°	21°	22°	22°			21°		21°
Yawing moments due to controls. (+) Favorable (−) Unfavorable	C_n $\alpha=0°$	.015		.002	.010	.016	.001	.006	.010	[e].003	.007	.010
			−.007	[f]−.003	[f]−.002		[e]−.001	[e]−.001				
	C_n $\alpha=10°$	.027		.004	.013	.018	.011	.016	.020	[e].016	.019	.022
			−.004	[f]−.002	[f]−.001							
	C_n $\alpha=20°$	.032			.008	.013	.013	.016	.021	[f].022	.022	[e].027
			−.010	[f]−.007	[f]−.006	[e]−.003		[e]−.002				
	C_n $\alpha=30°$	0				.002			.001			
		[e]−.003	−.008	−.008	[f]−.007	[f]−.004	−.016	[e]−.006	[f]−.003	−.012	[e]−.010	[e]−.004
Lateral stability[d] ($\delta=0°$)	α For initial instability in rolling		18°	18°	18°	18°						
	α For initial instability at $\frac{p'b}{2V}=0.05$: Yaw=0°		17°	17°	17°	17°						
	Yaw=20°		11°	11°	11°	11°						
	Maximum unstable C_λ: Yaw=0°		.048	.048	.048	.048						
	Yaw=20°		.093	.093	.093	.093						
Control force required	CF $\alpha=0°$	.008	.017	.019	.028	.041	.013	.006	.004	.003	−.003	−.006
	CF $\alpha=10°$	.002	.006	.005	.005	.010	.005	.002	.001	.002	−.001	−.002
	CF $\alpha=20°$	.002	.006	.003			.004	.001	.001	.002	−.001	−.002
	CF $\alpha=30°$		.007	.003								

Subject	Criterion	Standard ailerons and Spoiler E				Short, wide aileron[a]			
		Standard, $\delta_A=\begin{cases}25° \text{ up}\\25° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 1 $\delta_A=\begin{cases}35° \text{ up}\\15° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 2 $\delta_A=\begin{cases}50° \text{ up}\\7° \text{ down}\end{cases}$ $\delta_S=90°$	Up only, $\delta_A=60°$ $\delta_S=90°$	Standard, 25° up, 25° down	Differential No. 1, 35° up, 15° down	Differential, No.2, 50° up, 7° down	Up only, 60°
Wing area or minimum speed	$C_{L_{max}}$, $\delta=0°$	1.277	1.277	1.277	1.277	1.258	1.258	1.258	1.258
Speed range	$\frac{C_{L_{max}}}{C_{D_{min}}}$, $\delta=0°$	81.0	81.0	81.0	81.0	78.5	78.5	78.5	78.5
Rate of climb	L/D at $C_L=0.70$, $\delta=0°$	15.6	15.6	15.6	15.6	15.9	15.9	15.9	15.9
Lateral controllability	RC $\alpha=0°$	.249	.247	.252	.224	.226	.234	.226	.202
	RC $\alpha=10°$	.098	.096	.095	.088	.078	.084	.083	.076
	RC $\alpha=20°$	.052	.056	.067	.066	[b].046	[b].058	[b, c].073	[b, c].074
	RC $\alpha=30°$	.007	.019	.007	.008	.019	.025	.026	.022
Lateral control with sideslip	Maximum α at which controls will balance C_l' due to 20° yaw	20°	21°	21°	21°	19°	20°	22°	25°
Yawing moments due to controls. (+) Favorable (−) Unfavorable	C_n $\alpha=0°$		.004	.013	.019		.005	.016	.021
		−.003	[e]−.002	[e]−.002		−.007	[f]−.002	[e]−.001	
	C_n $\alpha=10°$	[e].004	.011	.020	.025		.006	.020	.026
						−.007	[f]−.003	[e]−.002	
	C_n $\alpha=20°$	[e].002	.006	.017	.023		.001	.019	.029
		−.002				−.010	[f]−.008	[f]−.007	[e]−.003
	C_n $\alpha=30°$							.003	.009
		−.012	[e]−.006	[e]−.006	[e]−.003	−.012	[h]−.009	[e]−.005	[e]−.002
Lateral stability[d] ($\delta=0°$)	αFor initial instability in rolling					18°	18°	18°	18°
	αFor initial instability at $\frac{p'b}{2V}=0.05$: Yaw=0°					17°	17°	17°	17°
	Yaw=20°					12°	12°	12°	12°
	Maximum unstable $C\lambda$: Yaw=0°					.022	.022	.022	.022
	Yaw=20°					.085	.085	.085	.085
Control force required	CF $\alpha=0°$	.013	.015	.024	.037	.030	.032	.052	.079
	CF $\alpha=10°$	.005	.004	.004	.009	.010	.007	.007	.014
	CF $\alpha=20°$	.005	.002			.009	.004		
	CF $\alpha=30°$					.011	.004		

See footnotes at end of table.

TABLE V—Continued

CRITERIONS SHOWING RELATIVE MERITS OF SPOILER AND AILERON COMBINATIONS—Continued

Subject	Criterion	Short, wide ailerons and Spoiler C				Short, wide ailerons and Spoiler D			
		Standard, $\delta_A=\begin{cases}25° \text{ up}\\25° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 1, $\delta_A=\begin{cases}35° \text{ up}\\15° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 2, $\delta_A=\begin{cases}50° \text{ up}\\7° \text{ down}\end{cases}$ $\delta_S=90°$	Up only, $\delta_A=60°$ $\delta_S=90°$	Standard, $\delta_A=\begin{cases}25° \text{ up}\\25° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 1, $\delta_A=\begin{cases}35° \text{ up}\\15° \text{ down}\end{cases}$ $\delta_S=90°$	Differential, No. 2 $\delta_A=\begin{cases}50° \text{ up}\\7° \text{ down}\end{cases}$ $\delta_S=90°$	Up only, $\delta_A=60°$ $\delta_S=90°$
Wing area or minimum speed	$C_{L_{max}}$ ($\delta=0°$)	1.208	1.208	1.208	1.208	1.270	1.270	1.270	1.270
Speed range	$\frac{C_{L_{max}}}{C_{D_{min}}}$ ($\delta=0°$)	75.0	75.0	75.0	75.0	78.0	78.0	78.0	78.0
Rate of climb	L/D at $C_L=0.70$ ($\delta=0°$)	15.7	15.7	15.7	15.7	15.3	15.3	15.3	15.3
Lateral controllability	RC $\alpha=0°$	.253	.234	.210	.183	.271	.265	.262	.231
	RC $\alpha=10°$	.101	.097	.090	.080	.110	.115	.108	.102
	RC $\alpha=20°$	.060	.065	.072	.074	.062	.071	.090	.088
	RC $\alpha=30°$	.013	.027	.029	.012	.020	.027	.024	.024
Lateral control with sideslip	Maximum α at which controls will balance C_l' due to 20° yaw		22°			20°	21°	23°	32°
Yawing moments due to controls. (+) Favorable (−) Unfavorable	C_n $\alpha=0°$	[e].002 [e]—.001	.007	.016	.022		.009 [e]—.002	.020 [e]—.002	.025
	C_n $\alpha=10°$	[e].012	.017	.025	.031	—.003 [f].008	.017	.030	.035
	C_n $\alpha=20°$	[e].015	.016	.026	.036	[f].007	.014	.034	.042
	C_n $\alpha=30°$	[f]—.010	[e]—.009	[f]—.009	.004 [e]—.007	—.012	[e]—.007	[e]—.007	.007 [e]—.004
Lateral stability [i] ($\delta=0°$)	α For initial instability in rolling								
	α For initial instability at $\frac{p'b}{2V}=0.05$: Yaw=0°								
	Yaw=20°								
	Maximum unstable $C\lambda$: Yaw=0°								
	Yaw=20°								
Control force required	CF $\alpha=0°$					.021	.023	.043	.070
	CF $\alpha=10°$					.007	.004	.001	.011
	CF $\alpha=20°$					.007	.002		
	CF $\alpha=30°$								

[a] Data taken from reference 1.
[b] Based on a lift coefficient 12 per cent lower than one on which other arrangements are based.
[c] RC has a minimum value of 0.036 at $\alpha=17°$ and a maximum of 0.079 at $\alpha=22°$.
[d] $RC=0.064$ at $\alpha=17°$ and 0.094 at $\alpha=22°$.
[e] to [h] Where the maximum yawing moment occurred below maximum deflection, the letters indicate the deflection of the up aileron or spoiler alone as follows: [e]=10°, [f]=15°, [g]=20°, [h]=25°.
[i] Lateral stability criterions unchanged by addition of spoilers since profile is continuous with controls neutral.